DYNAMICS MODELING AND SIMULATION FOR UPSET CONDITIONS

AirSC Technical Talk Series

19 May, 2004

OUTLINE

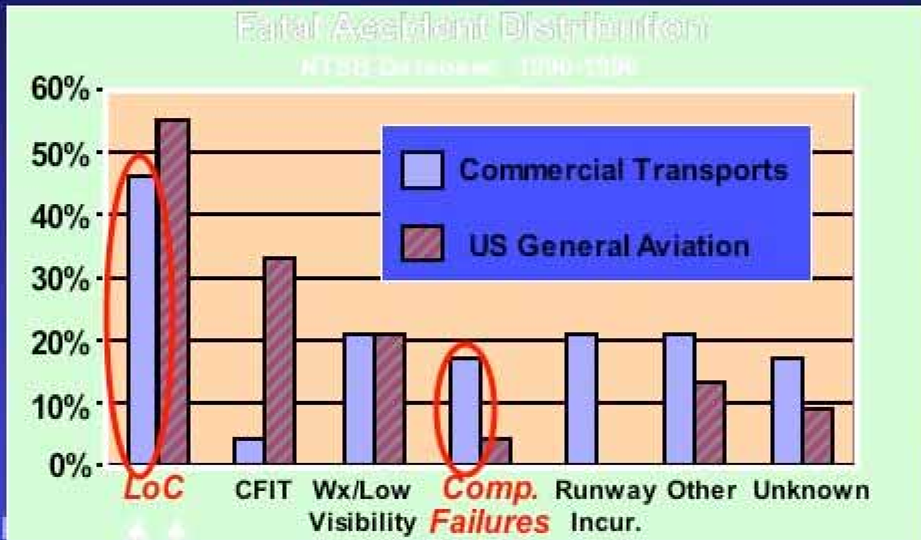
- Research motivation
- Experimental approach
  - Wind tunnel database development
  - Aerodynamic modeling
  - Validation
- Piloted simulation study
- Summary and plans

RESEARCHERS

- Kevin Cunningham — Real time piloted simulation
- John Foster — Dynamics Modeling
- Mike Fremaux — Wind tunnel testing
- Josh Keane (GWU) — Subscale model simulation
- Rob Rivers — Real-time simulation research
- Gautam Shah — Wind tunnel testing
- Eric Stewart — Dynamics modeling

SINGLE AIRCRAFT ACCIDENT PREVENTION

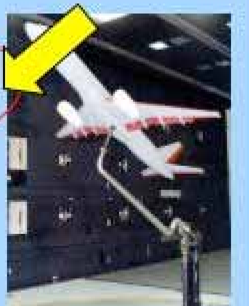
GOAL: Develop and Support the Implementation of Technologies to Enhance Aircraft Airworthiness and Resiliency Against Loss-of-Control in Flight



OBJECTIVES:

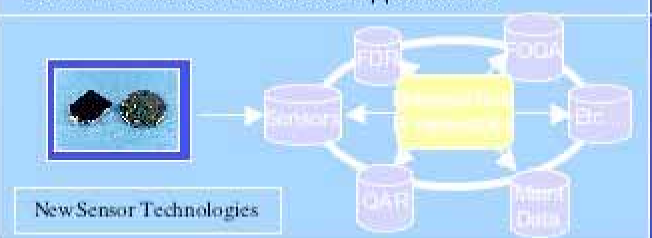
Prevent LoC from Unusual Attitude Conditions

- -Dynamic Aero Models of Unusual Attitudes
- -ReConfigurable Intelligent Control Systems
- -Guidance & Control for Auto-Recovery



Prevent Critical System & Component Failures

- -Advanced Sensor Applications
- -Model-Based Diagnostics/Prognostics
- -Crew Information/Workload Applications



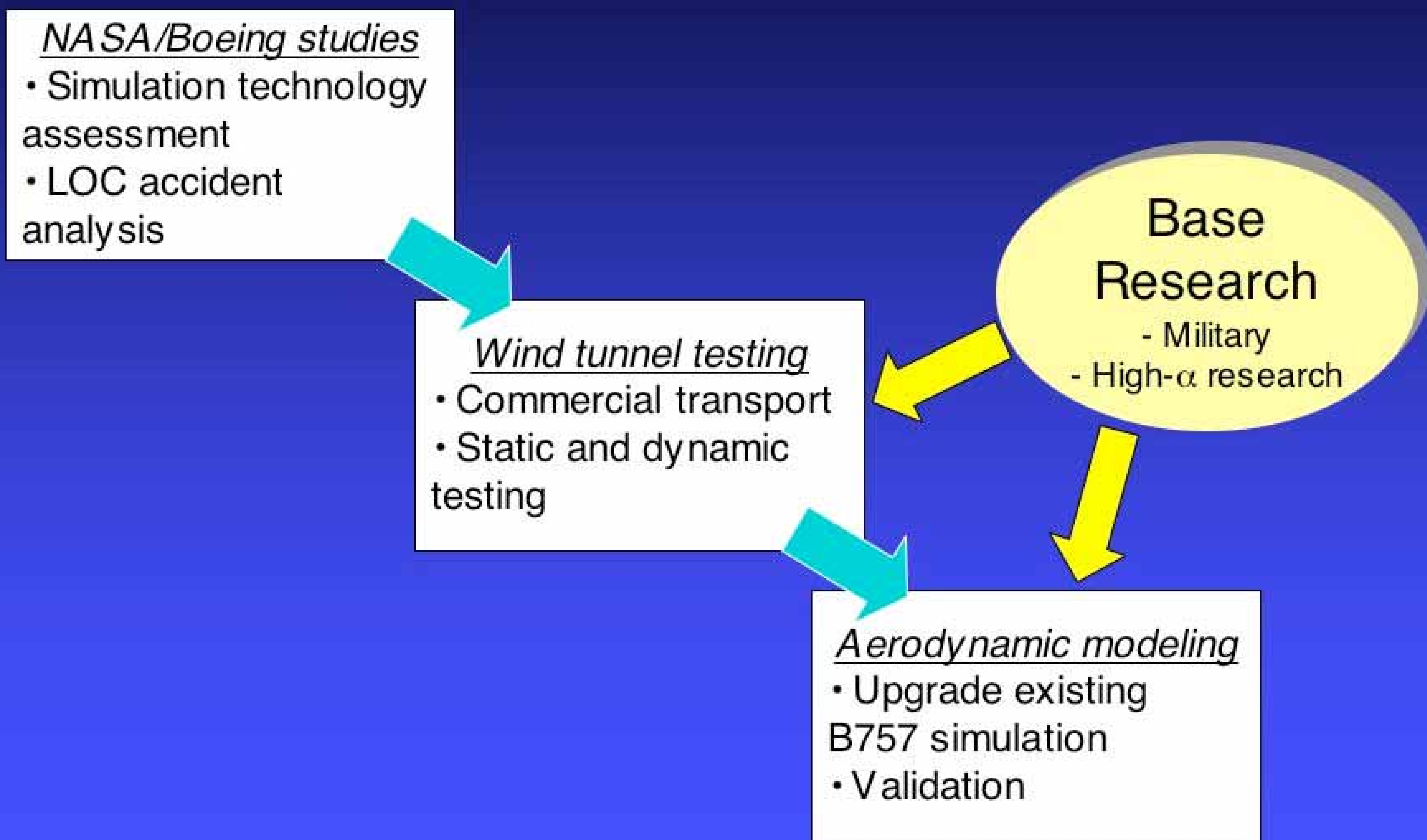
Prevent Inherent Design Flaws by Use of More Efficient V&V Tools

- -Fault Tolerant Integrated Modular Avionics
- -Formal Methods for Complex Sys Design Validation
- -Malfunction & Failure Accommodation Methods

MOTIVATION FOR DYNAMICS MODELING RESEARCH

- Simulation identified as an “intervention strategy” for reducing loss-of-control accidents
  - Industry working groups (JSAT, JSIT, etc)
  - NASA/Boeing studies
- Various applications as an “enabling technology”
  - Pilot training - recent upset training initiative
  - Advanced control system design (e.g. envelope protection)
  - Accident analysis and reconstruction

TECHNICAL APPROACH



FULL-SCALE PREDICTIONS USING SUB-SCALE MODELS

Sub-scale model

Similitude

requirements

Full-scale aircraft

- Rigorous modeling approach

  $C_i = f(\alpha, \beta, \delta, M, Re, \Omega l/V, k, t, \ldots)$

- Current approach

$C_i =$	$f(\alpha, \beta, \delta)$	(measured static data)
+	$f(M)$	(Mach number effects)
+	$f(Re)$	(Reynolds number corrections)
+	$\Omega l/V$	(rotary balance data)
+	$pl/V, ql/V, rl/V$	(forced oscillation data)

- <u>Current approach is a simplification !</u>

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WIND TUNNEL TEST SUMMARY

5.5% model on static mount
NASA LaRC 14x22 Ft Tunnel

Static

- 23,400 data points
- α: -30 to 90°, β: -45° to +45°
- Control and flap effects
- Landing gear effects
- Component effects
- Failure conditions

Forced Oscillation

- 3600 data points
- α : -10° to 90°, β : -45° to +45°
- Frequency and amplitude effects
- Control and flap effects
- Landing gear effects
- Component effects

5.5% model on roll forced oscillation rig
NASA LaRC 14x22 Ft Tunnel

Rotary Balance

- 16,000 data points
- α : 0° to 90°, β : -45° to +45°
- Rotational rate effects
- Control and flap effects
- Landing gear effects

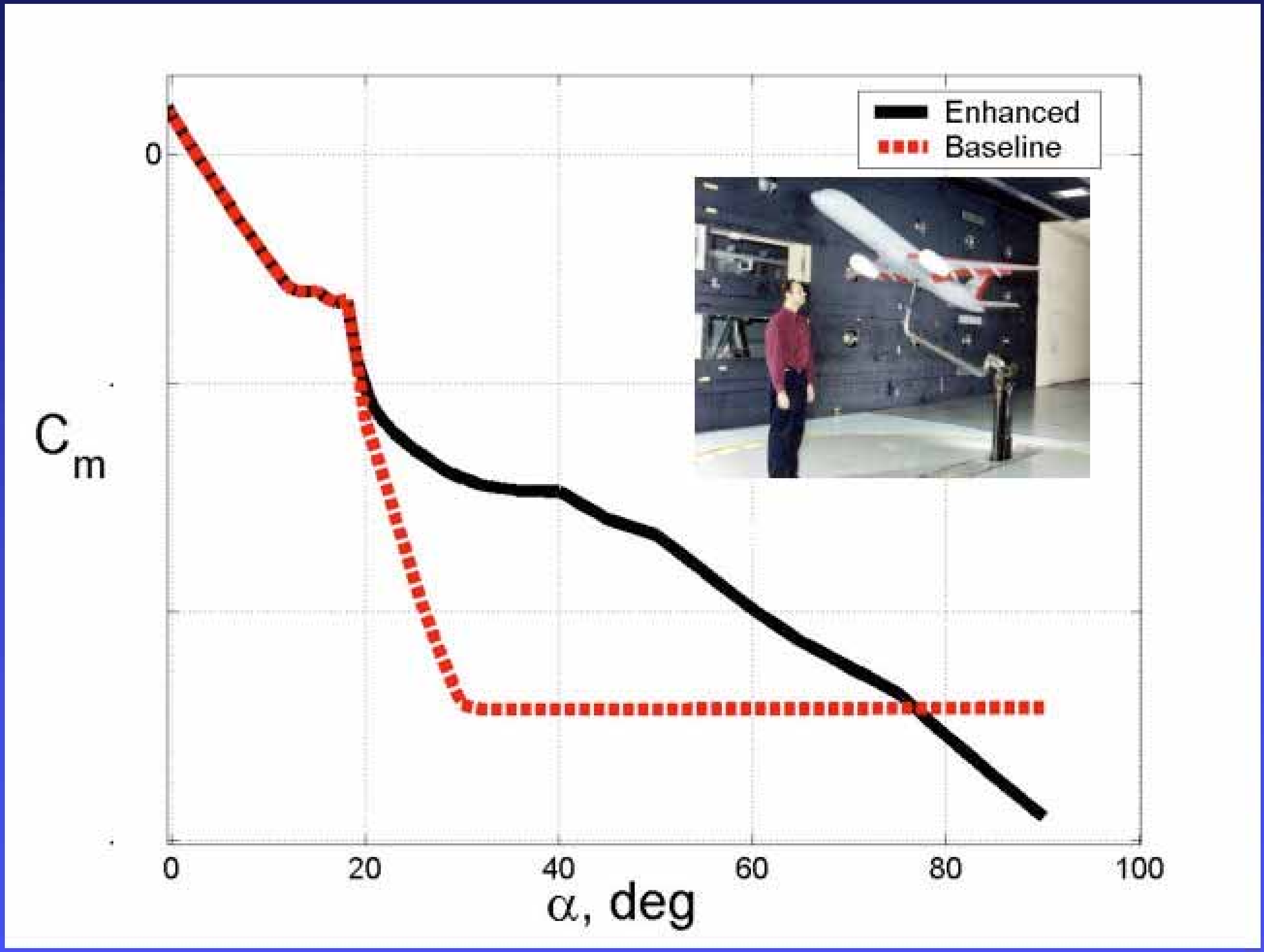
3.5% model on rotary balance rig
NASA LaRC 20 Ft Vertical Spin Tunnel

AERODYNAMIC MODEL NOMENCLATURE

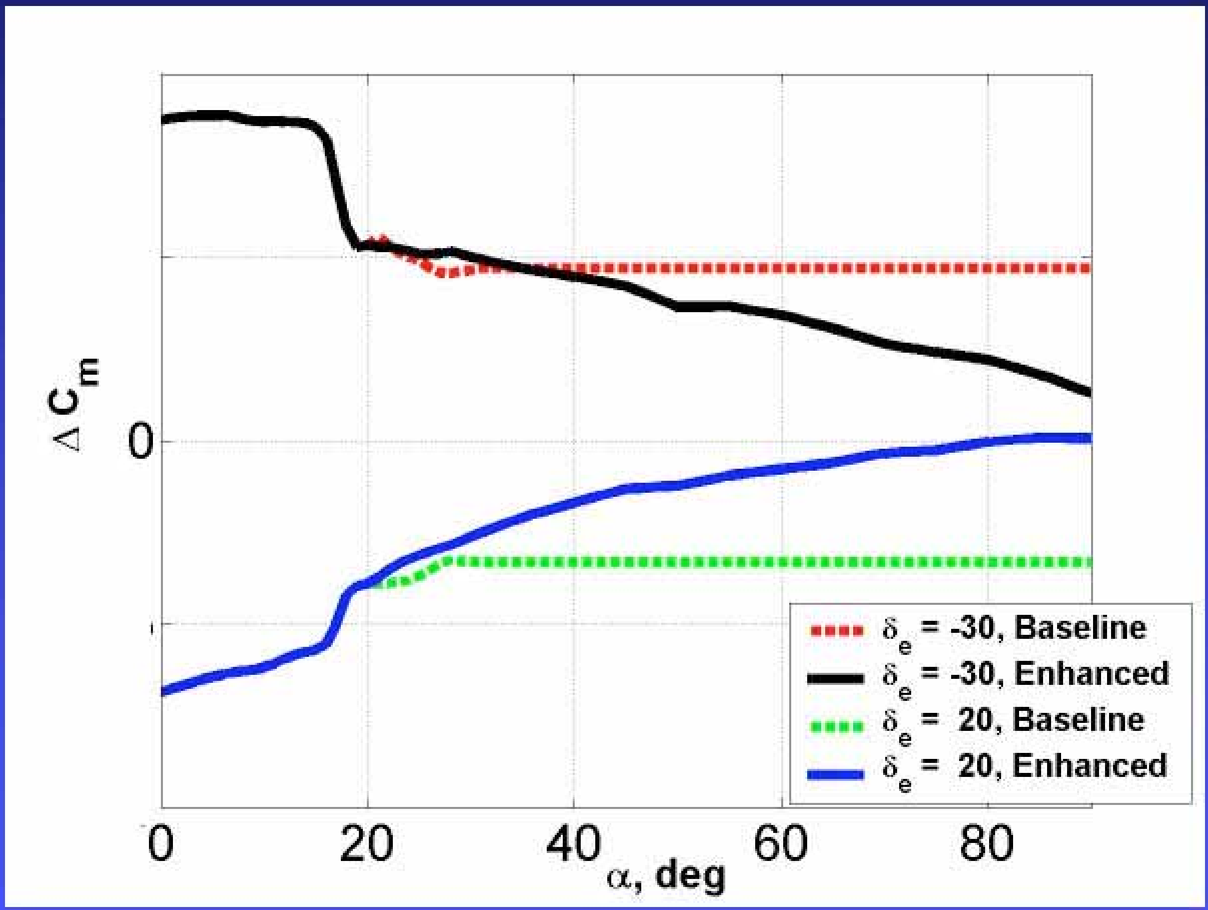
- Rev J
  - Baseline B757 training simulation

- Enhanced upset recovery (EUR) (M<0.4)
  - Enhanced static data
  - Non-linear rate damping model

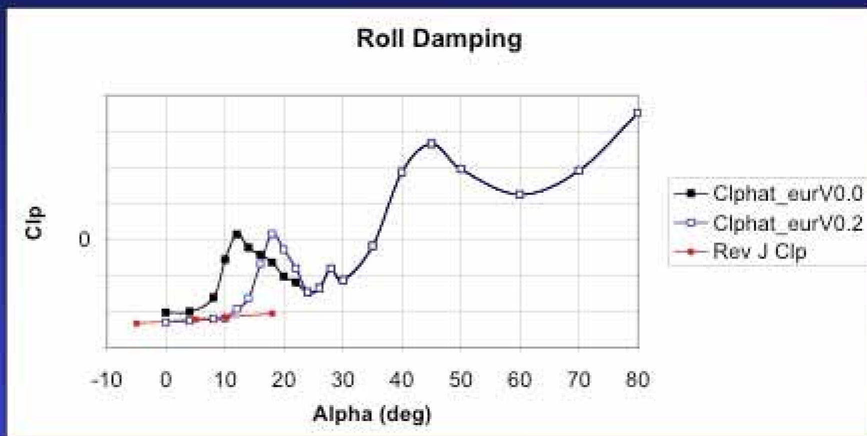
ENHANCED STATIC AERO MODEL

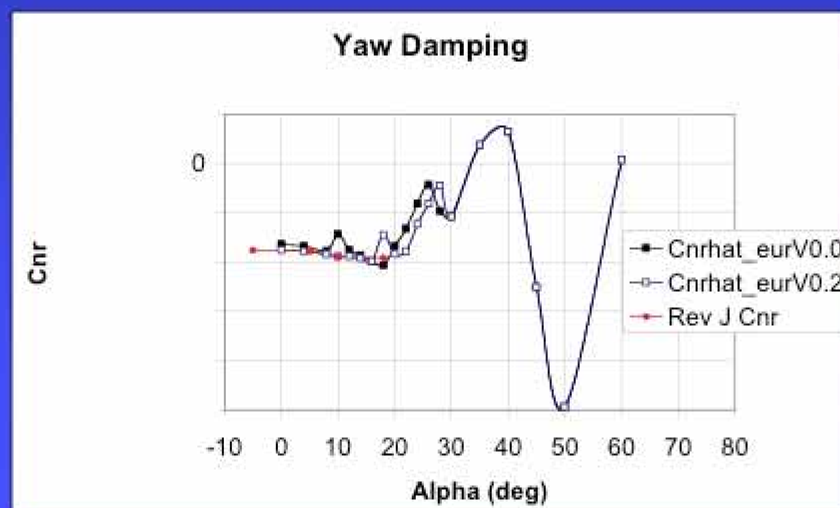


ENHANCED PITCH CONTROL MODEL



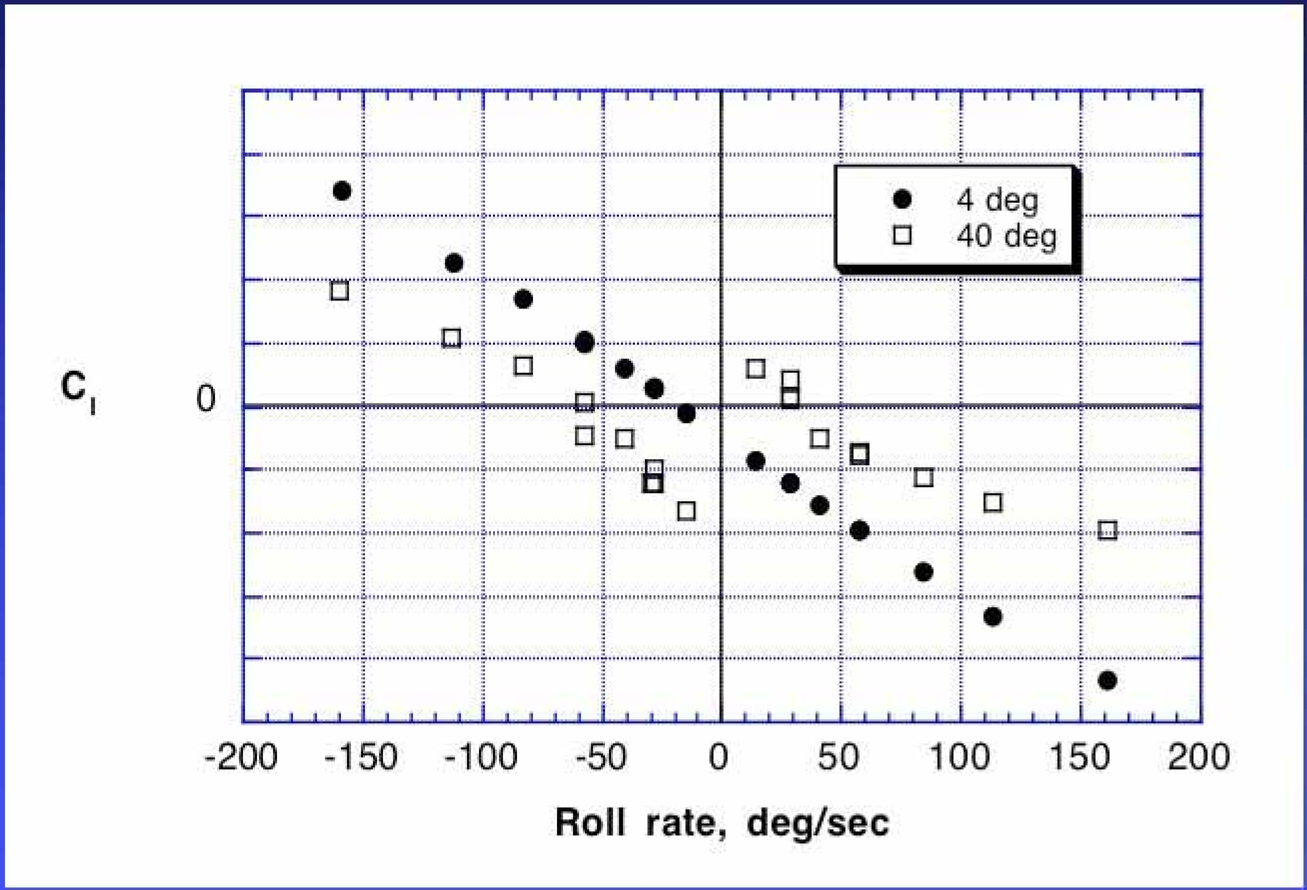
ENHANCED RATE DAMPING MODEL
(Linear Derivatives)





Baseline
Wind tunnel
Enhanced simulation

NONLINEAR RATE DAMPING EFFECTS
Forced Oscillation Results



LINEAR MODEL INADEQUATE FOR UPSET CONDITIONS

COMPARISON OF SIMULATION TO FLIGHT DATA

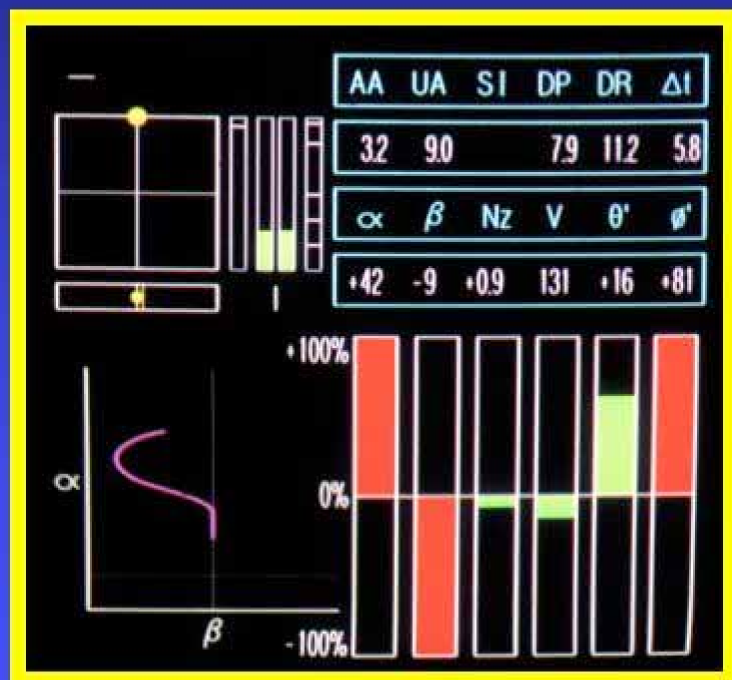
NASA INTEGRATION FLIGHT DECK (IFD) SIMULATOR

- Representative of LaRC B757 research aircraft
- Numerous modifications for UPSET project
  - Research displays
  - Stick shaker
  - Ability to rapidly modify aerodynamic database
  - Emulate failure scenarios
  - Playback capability
- Designed to provide highly flexible tool for stability and control research

RESEARCH DISPLAY

•Pilot Inputs
- Wheel / Column
- Pedal / Rudder
- Spoiler
- Throttles
- Flaps
- Trim Switches
- A/P Disconnect

•Upset / LOC quantification
- Envelope labels
- Exceedence times
- Critical/Recovery time

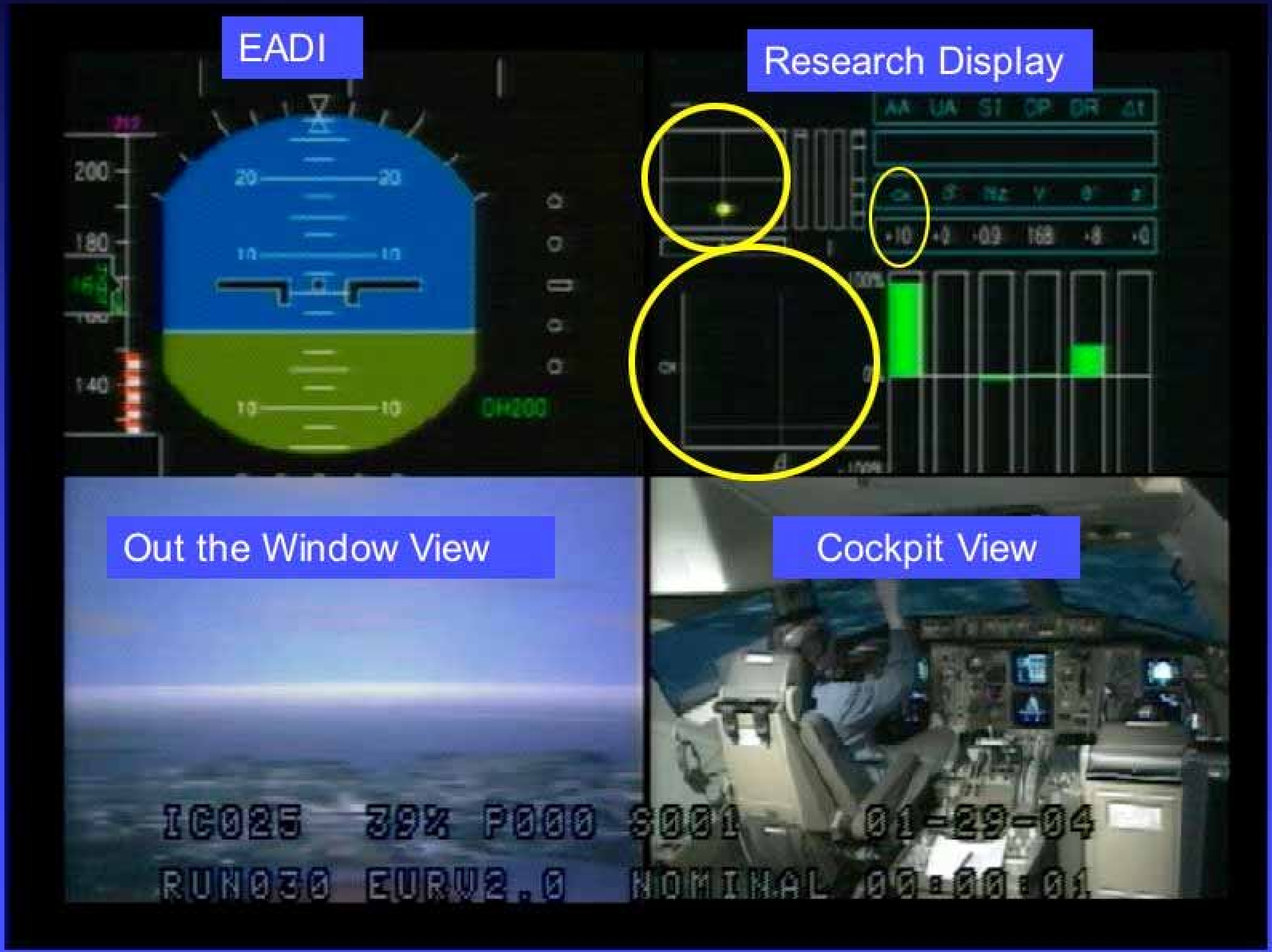


• Aircraft state information
- Labels
- Numeric Data

•Aerodynamic State
- Current
- Event History

•Graphical State Info
- Relative to LOC envelopes

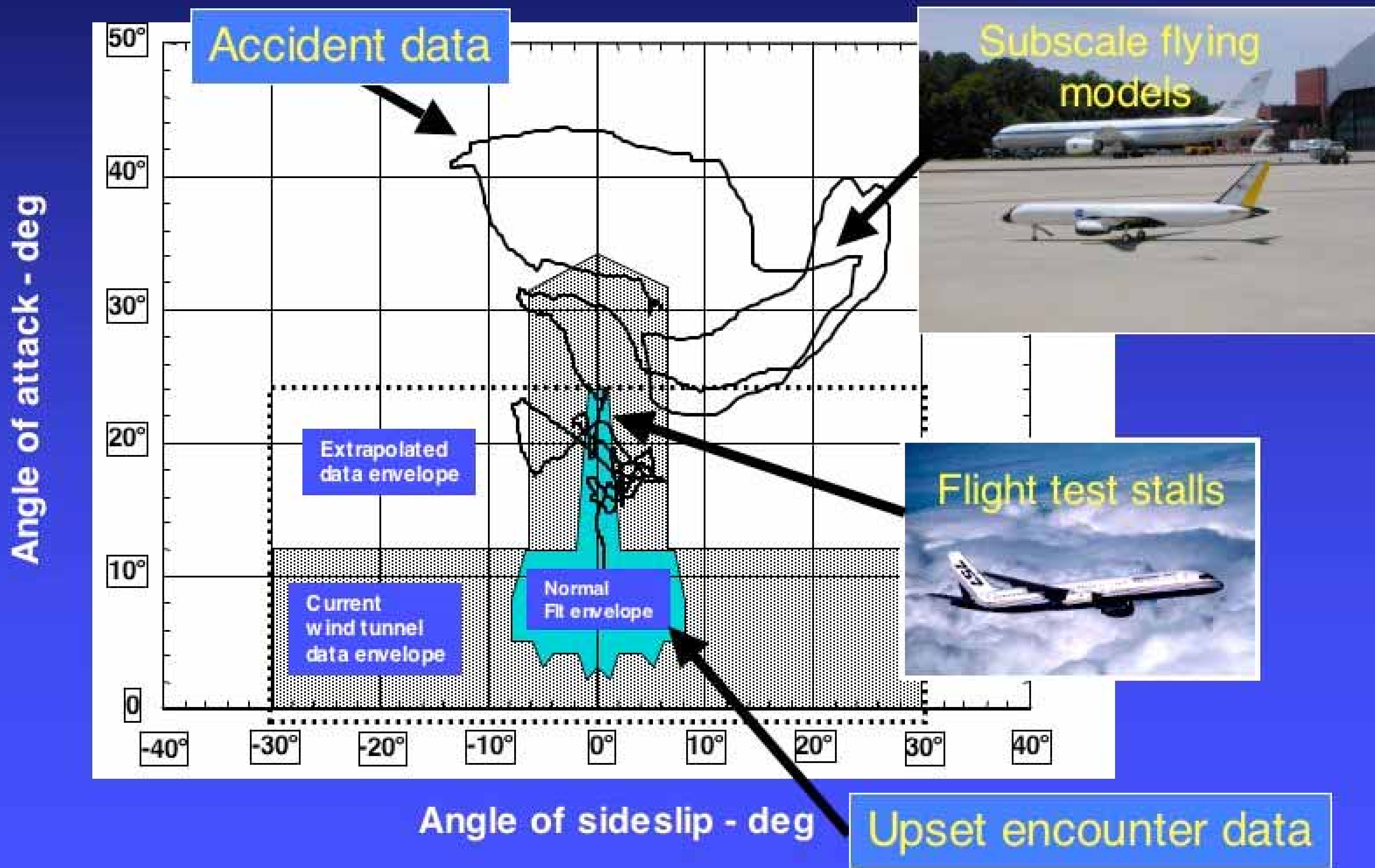
QUAD VIEW FAMILIARIZATION



VIDEO

- LaRC B757 real-time simulation
- Comparison of aerodynamic models
  - Baseline
  - Enhanced
- Response to full aft column input
- Configuration
  - Aft cg
  - Yaw Damper: Inoperative

PROPOSED SIMULATION VALIDATION APPROACH FOR UPSET CONDITIONS



SUMMARY

- Simulation fidelity of transport airplanes for upset conditions can be significantly improved
  - Well-accepted experimental methods for aerodynamic measurements applicable to loss-of-control/upset conditions
  - Recent advances in aero modeling technology enable robust upset simulation
- Further research on high-α aerodynamic modeling unique to large transports needed
- Validation of simulation fidelity for upset conditions remains a challenge

FUTURE PLANS

- Support development and integration of enhanced upset training "tools"
    - Industry and airline pilot participation
- Conduct detailed validation of enhanced aero models for upset conditions
    - Accident and flight test data
    - Subscale flying testbed
- Conduct wind tunnel testing to develop aerodynamic database for range of transport configurations